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MEASUREMENTS OF MAGNETIC PROPERTIES OF DIGITAL VERTICAL RECORDING MEDIA BY OPTICAL MEANS

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ABSTRACT:

The magneto-optic Kerr effects can be used to test the magnetic properties of thin film data recording media rapidly and non-destructively. A computer controlled instrument has been built to evaluate most vertical magnetic media, even those exhibiting weak magneto-optic properties such as Cobalt-Chrome.

Magneto-optical phenomena

The various magneto-optic effects, which we will be describing here, refer to changes induced in the polarization of a light beam impinging on a medium and attributable to the magnetic properties of the medium. For clarity, the effects are often separated into the effect on a light beam reflected by the media, known as the Kerr effect, and the effect on light passing through the magnetic media, known as the Faraday effect as indicated in figure 1.

The magneto-optic behaviour of materials can be quantitatively understood by mathematically describing a particular material with its appropriate dielectric and permeability tensors and then solving Maxwell equations in that medium after specifying the proper boundary conditions [1-3]. Unfortunately, although this approach yields a very detailed and accurate description of the magneto-optic effects, this mathematically oriented description of the phenomenon can lead to very complex expressions which easily mask the phenomenological results. A non-rigorous description is more appropriate to get a grasp of the concepts involved.

A polarized beam of light impinging on a magnetic material has its state of polarization modified after reflection from or transmission through a magnetic medium, see figure 2. Measuring the changes in the polarization state of the light enables us to quantify the magnetic properties of the material. For simplicity it is advantageous to start with a well defined and easy to obtain polarization state of the light. For example, a linearly polarized light beam has its reflected and transmitted light components changed to elliptically polarized light, i.e. the component of the E field vector orthogonal to the original light E field vector orientation is no longer zero after interaction with the magnetic material. The second important observation with respect to the magneto-optic effect is that it is proportional to the magnetic moment of the material and changes sign with the material magnetization orientation.

Figure 3 defines some of the magneto-optic nomenclature commonly used with respect to orientation of the various elements. A standardized terminology is necessary because of the infinite variations possible between the orientation of the impinging light beam, the spatial orientation of the material and the orientation of the magnetization within the material.

Measurement assumptions and limitations.

Due to the sensitivity of the method, the traditional way of testing the magnetic properties of data recording material has been the VSM (Vibrating Sample Magnetometer), or one of its variations, particularly for thin films [4]. Unfortunately, the method is slow, partly because it is necessary to generate a spatially large and even magnetic field within a magnet gap of several inches. Furthermore, it is often a destructive method because of the size restrictions imposed on the sample. This is a severe limitation to the usefulness of the method since cutting a digital recording disc destroys its usefulness for any other purpose than a test sample. Another common test has been the recording of known data with a check on the integrity of recovered data at playback time. This is an effective means of measuring the error rate of the entire system but is unsatisfactory to evaluate a recording medium since it is impossible to distinguish between magnetic errors related to magnetic material, and those related to other components of the system such as disc flatness, surface finish, servo tracking etc.

The magneto-optic testing method does not suffer from these limitations. However, it should be emphasized that no single magnetic measurement method is universally applicable. Each measurement technique provides its own useful observation window and clearly a choice must be made by the experimentalist in view of his own particular circumstances. The Kerr effect magneto-optic testing method offers a means of probing the magnetic characteristics at and near the surface of the material, while the VSM provides information averaged over the volume of the sample. In addition, the spatial area probed can be manipulated at will. For example, it is possible to probe a relatively large area in order to acquire information on the average magnetic moment of the material then probe for small localized spatial variations of the magnetic moment due for instance to local film defects. Unlike testing with an inductive magnetic read head, a magnetic hysteresis loop can be obtained at any point, separating the magnetic information from the extraneous system information.

A possible limitation of the system is the assumption that there is no uncontrolled thin film material at the surface of the magnetic material, eg. a thin layer of spotty contaminant. Such a thin film would affect the magnitude of the Kerr effect in localized areas and be undistinguishable from magneto-optic effects [5-6]. Note that, if the thin film stack superimposed to the magnetic material is controlled, useful Kerr effect enhancement can be obtained [7-8].

Magneto-optic effects detection and noise sources.

When a beam of polarized light is passed through a polarizer, called in this instance an analyzer, the average E field intensity is proportional to the cosine of the angle between the incoming E field vector and the axis of the polarizer.

The photodetectors do not respond directly to the E field amplitude but the square of the electric field vector components, i.e. it responds to power in accordance to the Poynting energy vector. Therefore the average light power at the detector is proportional to the square of the sine of the angle of transmission through the analyzer from the minimum transmission point before the light is modified by the magnetic material.

The amount of ellipticity introduced by a magnetic material always tends to be small, including those magneto-optic materials considered useful for digital optical storage [9-10]. A Kerr rotation angle of 2 degrees is exceptional. Materials useful for inductive vertical recording such as Cobalt-Chrome alloys seldom exceed 5 minutes of arc total rotation. Even though a main attraction of magneto-optic techniques as means of high density digital information storage is the ability to improve the signal-to-noise ratio merely by increasing the power of the incoming beam of light, there is an upper limit to the power which can be applied. Ultimately, permanent changes could be induced in the material being interrogated, or, in our case, erroneus results could be induced from temperature changes in the magnetic hysteresis curve of the media.

The main sources of noise are: the thermal noise current (Johnson noise), the shot noise due to the statistical nature of light which is quantized, light source noise, due for instance to the statistical and thermally induced fluctuations in a laser, and last noise due to the media such as light scattering by surface defects or the presence of a thin extraneous film. For digital recording applications, after taking in consideration practical matters like an attractive cost / performance ratio with respect to other technologies, a rotation of 0.5 degree and above is practical. In the case of a magneto-optic probing instrument, there is no choice for a favourable material. Furthermore, a complete hysteresis curve is expected instead of merely detecting the saturated extremes of the hysteresis curve. Oustanding detection techniques become necessary at the expense of added complexity or bandwidth reduction or both.

Simple magneto-optic signal detection schemes.

The simplest detection method makes use of the ease in detecting the extinction of a linearly polarized beam when a polarizer axis is place orthogonally to the light polarization plane (2). This gives the reference point to measure angles. If an optically isotropic material is temporarily substituted for the magnetic material, the null point is easily found. The magneto-optically induced rotation can be calculated from measuring the power at a known rotation angle of the polarizer, i.e. by finding a maximum if the detector has enough dynamic range to avoid saturation, or by measuring the angle directly with a vernier i.e. by finding the null after placing the magnetic material in the path and comparing to the previous position. In order to distinguish between positive and negative knowledge of its internal operation to calibrate the results.

The polarization modulation is digitally generated and an analog-to-digital converter constantly monitors the result, which therefore puts the modulation amplitude under close-loop control this compensates for any deterioration due to aging of the components or for any temperature drift which could occur. The computer waveform generator directly drives an amplifier which supplies the Faraday rotator. The Faraday cell consists of a special glass rod with high Verdet constant placed inside a solenoid generating the large time-varying magnetic field necessary to create the magneto-optic anisotropy in the glass [18]. The modulation frequency is quartz controlled, which later facilitates synchronous detection of the signals since its frequency and phase are accurately known at all time.

An electro-magnet generates the magnetic field in which the magnetic medium is placed. The magnet was designed to be air-cooled and can be swept between + 12 kgauss if necessary. A large bipolar amplifier is used to generate the drive current. The data for a complete hysteresis loop can be acquired in as little as 1 second for a magnetic field sweep of + 8 kgauss, and an estimated + 3% accuracy on Cobalt-Chrome exhibiting a rotation of + 4 minutes of arc. Typically the sweeptime is extended to 5 seconds to improve the data resolution and accuracy. This favorably compares with typical hysteresis loop data acquisition times of 10 to 30 minutes for a Vibrating Sample Magnetometer. The actual magnetic field in the electro-magnet gap is sensed by a small Hall effect generator. The signal is amplified and digitized then the information fed back to the computer for a closed loop control of the magnetic field.

The data generated by the POKE system can be displayed either on the computer's CRT, on a dot matrix printer or on a plotter. Data averaging and other data smoothing techniques can be used for special applications. The data can also be stored on a floppy disc drive for future reference or comparison with other data. Then automatic extraction of, for instance, the coercivity or any other hysteresis loop related data is easily accomplished.

Conclusion.

A computerized magnetometer designed to non-destructively test vertical digital magnetic media discs has been built using an indirect magneto-optic measurement technique. The Kerr effect hysteresis curve obtained is somewhat similar to the familiar hysteresis B-H loop obtained with a VSM. However, while the B-H loop is purely a function of the magnetic moment of the material tested, care must be exercised because the Kerr effect hysteresis loop can carry other information. Since the Kerr effect amplitude is directly proportional to the magnetic moment, the data can readily be used if other factors potentially affecting the amplitude of the magneto-optic effect are held fixed. For example the wavelength of the interrogating light beam as well as the optical surface conditions of the film must be held fixed during the measurement. These conditions are met in the POKE instrument, and furthermore, each polarization rotation vs magnetic field hysteresis curve is calibrated for the prevailing reflectivity conditions of each run by manipulating the amplitude of the orientation of the magnetization vector, the reference axis position is shifted by a known but small angle larger than the maximum expected rotation. Another detection method refered to as the differential method uses two analyzers equally shifted about the null position. The analytical results are the same than for the single analyser method except for an improvement in signal to noise ratio with respect to laser and reflectivity noise. The media surface noise is caused mostly by diffraction of the light by small defects such as small depressions or dust particules on the film surface. Because this scattered light is essentially depolarized, it is eliminated as common mode in the differential detection mode. It can be shown that shot noise is independent of small polarization angles and essentially dependent only on the illumination intensity and desired signal bandwidth at the detector. Instead of working at small angles near the null point, setting the analyzers at 45 degrees from null in a differential mode gives a response which is linear with respect to the rotation angle for small rotation angles. Unfortunately, working at a 45 degree angle also means that the light source power is equally divided between the detectors which are then swamped by a large signal that has no information content. If detector saturation can be prevented, the common mode signal can then be eliminated electronically by a differential amplifier. This usually implies limiting the laser power, hence increasing the shot noise, which is undesirable since the bandwidth must then be cut to preserve the signal-to-noise ratio.

<u>Detection schemes to improve the signal-to-noise ratio</u>

Various methods to improve the signal-to-noise ratio have been recently proposed [11-13]. Variations of these schemes are well known and have been used for some time in communication systems applications with laser polarization modulation [14], or in ellipsometric instrumentation [15-16]. The basic idea is to superpose the magneto-optic information over a polarization component alternating periodically. Either the polarization ellipticity or the polarization azimuth can be modulated. This method allows synchronous signal detection and is amenable to narrowband filtering techniques to improve detection sensitivity and reduce the shot noise. In other words, the signal detection bandwidth can be narrowed to improve the signal-to-noise ratio. The polarization ellipticity modulation is accomplished with an electro-optic Pockell cell or a piezo-birefringent modulator. The former has the advantage of a modulation carrier frequency potential in the gigahertz region, but is more difficult to handle. The polarization azimuth modulation can be accomplished by mechanically rotating or oscillating a polarizer on axis. The same effect can be obtained electronically with a magneto-optic Faraday modulator. In either case the technique is not yet readily amenable to the very high modulation carrier frequency which would be necessary in a digital storage system.

Several configurations of the optic train varying the position of the polarizer, analyzer and modulator are theoretically possible, similar to the unmodulated carrier case. The differential detection scheme can also be used as in the unmodulated case, with the same benefits towards surface noise rejection. Using sinusoidal polarization modulation, a reference signal can be created by sampling the modulated beam before it reaches the magnetic material. The reference signal is then electronically substracted from the signal which has been rotated by the magnetic material [17]. This detection method directly yields a signal at the modulation frequency whose amplitude is proportionnal to the polarization rotation. The signal is very low in even harmonics assuming an ideal differential amplifier. However if signal detection bandwidth is not critical synchronous detection will achieve the same results since synchronous detection is completely insensitive to even harmonics.

POKE (Polar Kerr Effect) system configuration.

A computer based system has been built specifically to acquire magnetic hysteresis loops at speeds sufficient to make the instrument usable as a quality control device on a production line and to simultaneously have the accuracy necessary for a research tool, figure 4. A polarization azimuth modulation based on a Faraday cell has been chosen because it is the simplest to model mathematically and has a speed adequate for an instrumentation application.

A 5mw polarized He-Ne laser operated in the Tem 00 mode at 632.8 nm is used as a convenient light source. For packaging convenience of the instrument, the beam is folded with two prisms, then the beam is passed through a spatial filter which smooths out its intensity profile by removing the high frequency spatial components. A half-wave plate is inserted at this point for convenience in repositioning the polarization axis with minimum losses. Although the laser beam is already polarized as it exits the front mirror of the laser, it is nevertheless passed through a high quality Glan-Thompson calcite prism polarizer to obtain a deeply linearly polarized beam. The beam is then polarization modulated by passing through the Faraday cell. The beam is sampled to become the optical reference channel while the majority of the power is directed normal to the surface of the recording disc under study. The disc is placed between the poles of an electromagnet capable of reaching 12 kgauss in either magnetization polarity. The beam reaches the surface of the disc through a controlled aperture drilled in one pole of the magnet. After reflection by the magnetic material, the beam is folded to reach the photodetector of the measurement channel. Both reference and measurement channels are focused onto a very low noise photodetector after passing through their respective analyzers. Glan-Thompson analyzers with a high extinction ratio are placed in a finely rotatable mount. All optical surfaces are coated with an anti-reflection thin film to avoid unnecessary optical power losses.

Computer interface

The POKE system is entirely computer controlled to relieve the operator from any knowledge of magneto-optics or even computer operation. The machine is menu driven and merely requests the operator to specify which type of data is desired and how it must be presented. The computer controlled POKE evolved from an analog based ancestor which demanded intimate polarization modulation.

The definite advantages of the magneto-optic method are to provide a quick non-destructive and spatially selective means of probing the magnetic characteristics of a magnetic medium. It becomes an irreplaceable method if this magnetic medium is underlaid with another magnetic material, as is often the case for magnetic vertical recording media underlaid with a soft magnetic layer.

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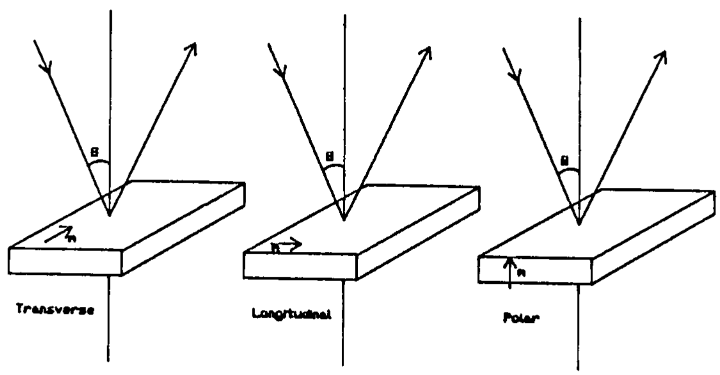

Fig. 3 Definition of the Orientation Vectors for the Light with Respect to the Material and Its Magnetization Vector

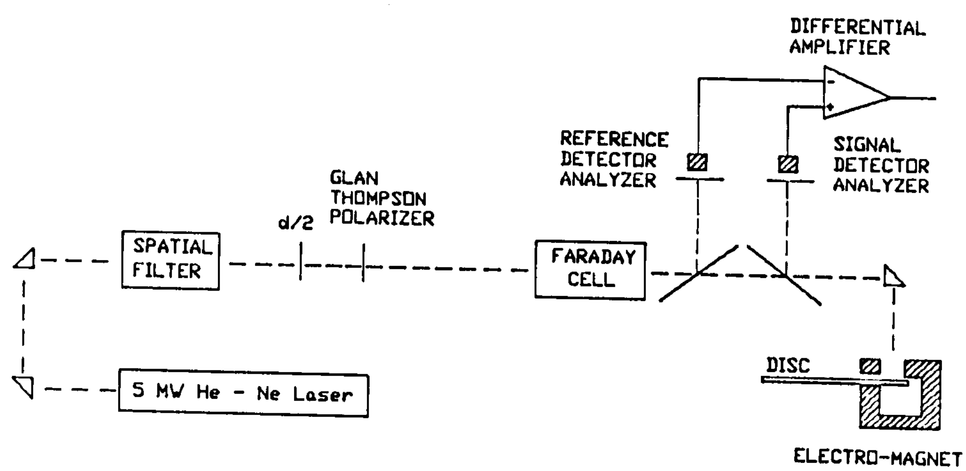

Fig. 4 POKE System